Tree Canopy Cover in Wellington City and Suburbs, New Zealand

Report prepared for the Wellington City Council
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UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha

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Executive Summary

Tree canopy cover (TCC) is an important way of describing urban forests and is necessary to assess the ecosystem services they provide. Tree canopy cover was estimated for Wellington City and Suburbs using an object-based image analysis (OBIA) approach, followed by manual correction.

The OBIA was based on aerial orthophotography and LiDAR data acquired over Wellington between 2017 and 2020. The tree canopy cover assessment that was completed for this report should be considered accurate as at 20 March 2019, the date of the earliest LiDAR data acquisition.

Overall tree canopy cover in Wellington City and Suburbs is 30.61%. Tree cover in wards ranges from approximately 20 – 47%, while in suburbs it ranges from a low 1% in Rongotai to a high of 71% in Highbury. Two-thirds of the suburbs in the study area have tree cover ranging between 10 – 40%. Only two suburbs (5% of suburbs) have tree cover greater than 50%, while 6 (14% of suburbs) have tree cover less than 10%. The accuracy of the classification is 98.36%.

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Background

The Wellington City Council (WCC) expressed a need to understand the extent and location of existing tree canopy cover in the city. Tree canopy cover (TCC) is the total area of tree crowns projected onto the ground and is expressed as a percentage of total ground area.

Tree canopy cover is the most widely used descriptor of urban forest structure. Because of this, knowing the tree canopy cover in Wellington City and its suburbs will allow decision makers to compare TCC in Wellington with that of other cities in New Zealand and abroad. It will also allow decision makers to monitor TCC changes in Wellington over space and time to ensure desirable levels of TCC exist throughout the city. Knowledge of tree canopy cover can also help to evaluate the potential impacts of TCC gains or losses, help to enforce bylaws or conservation requirements during development, or inform zoning and land use planning. It can also help with public buy-in by educating public officials and citizens about the importance of tree cover.

Methodology

Study Area

The study area, called Wellington City and Suburbs, was defined by the overlapping areas of aerial photography and LiDAR data (Figure 1). This included parts of 5 wards and 56 suburbs. Slightly more than 40% of the total area covered by all these wards and/or suburbs are included in the study area. With respect to wards, tree cover analysis was undertaken for Eastern, Lambton, and Southern in their entirety; but only 21.4 and 35.6% of Onslow-Western and Northern Wards, respectively, were within the study area (Table 1). For suburbs, the variation in total area covered by the study area varies considerably (Table 2). For example, 0.5% of Makara, 38% of Brooklyn, and 100% of Aro Valley were included in the study area.

Object-based image analysis

Tree canopy cover was mapped throughout Wellington City and Suburbs using an object-based image analysis (OBIA) approach. OBIA is a semi-automated image classification method that can be used to identify trees based on aerial photography and LiDAR data. Aerial photography provides spectral reflectance values in the red, green, and blue visible light wavelengths for each pixel. LiDAR point data were interpolated into a normalised digital surface model, from which height values were extracted.

OBIA combines two processes: 1) segmentation, and 2) classification. It begins by segmenting images into 'objects' by minimising the within-object variation in red, green, and blue spectral reflectance values, as well as height values. Once objects are established, each object is assigned to a land cover class (e.g. tree, grass, building) based on the reflectance and height values. This latter process is called classification.

Definition of a tree

For the purpose of the OBIA, a tree was defined as an object having vegetation-like reflectance characteristics, exceeding 3.5 m in height and having a minimum diameter of 1. 5 m. Remote sensing analyses, like this one, are constrained by the available data and thus must use a definition based on spectral reflectance and structure of objects, rather than a biologically acceptable definition of a tree.

The thresholds of 3.5 m height and 1.5 m diameter were selected for three purposes. Firstly, the ecosystem services provided by trees generally increase with tree size, so including smaller trees in this analysis would not contribute further to an understanding of the ecosystem services provided by the urban forest in Wellington City and Suburbs. Secondly, reducing these thresholds would decrease the accuracy of the tree cover classification by introducing error associated with other shorter, similarly-sized objects (e.g. vehicles, garden sheds, fences, etc.). Thirdly, the nominal spatial resolution of the aerial photography and, especially, the LiDAR data preclude reducing these thresholds significantly.

All tree cover areas reported below are inclusive of all tree and forest types. This includes, but is not limited to, park and reserve trees, street trees, trees on private property, orchards, remnant patches of native forest, hedgerows, and trees in commercially-managed, large-scale forestry plantations.

Manual refinement of OBIA

Following the OBIA, tree canopy cover was manually refined to correct errors in the tree cover classification. More than 213,000 polygons classified as trees by the OBIA were manually checked to determine if they resulted from commission errors (objects that were classified as trees, but should not have been). Further to that, omission errors (objects that were not classified as trees, but should have been) were identified. Objects resulting from errors of commission were deleted, while objects resulting from errors of omission were reclassified. There were more than 10,000 objects requiring boundary adjustment; these were manually corrected at a scale of no greater than 1:2,500.

Imagery used in the analysis

Aerial photography was captured by AAM NZ Ltd. for the Wellington City Council during the summer of 2016-17. Images were acquired on 24, 27, 28 February and 5 March 2017. Imagery was supplied as 10 cm pixel resolution, 3-band (RGB) uncompressed GeoTIFF. The final spatial accuracy is ± 0.2 m at 90% confidence level. LiDAR data were captured for Wellington City Council by Aerial Surveys from 20 March 2019 to 14 March 2020. As a consequence of the range in time of acquisition for LiDAR data, the tree canopy cover assessment that was completed for this report should be considered accurate as at 20 March 2019. Both aerial imagery and LiDAR data were sourced from the LINZ Data Service and licensed by Wellington City Council, for re-use under CC BY 4.0.

Ancillary boundaries used in the analysis

In order to produce tree canopy cover estimates (see Results below), boundaries for areas of interest were needed. As described in the Study Area section above, only land areas were considered. The suburb and ward boundaries were provided by the Wellington City Council.

Accuracy Assessment

The quality of the tree canopy cover map was determined by means of a formal accuracy assessment. The accuracy assessment uses a standardised approach, comparing what has been mapped as tree canopy cover with what actually exists in the aerial photographs. Two-thousand five hundred sample points were randomly distributed within the study area and each of these was assigned a 'reference' land cover based on what was observed at the location defined by each point in the aerial photography and LiDAR data. The 'reference' land cover is the true land cover. Each point was also assigned a 'classified' land cover based on what was mapped by the OBIA at the location defined by each point.

The result of the accuracy assessment is an error matrix that quantifies the overall accuracy of the OBIA classification as well as the errors of commission (land that was classified as tree cover, but shouldn't have been) and errors of omission (land that was not classified as tree cover, but should have been). These terms are further defined in the Glossary at the end of this report.

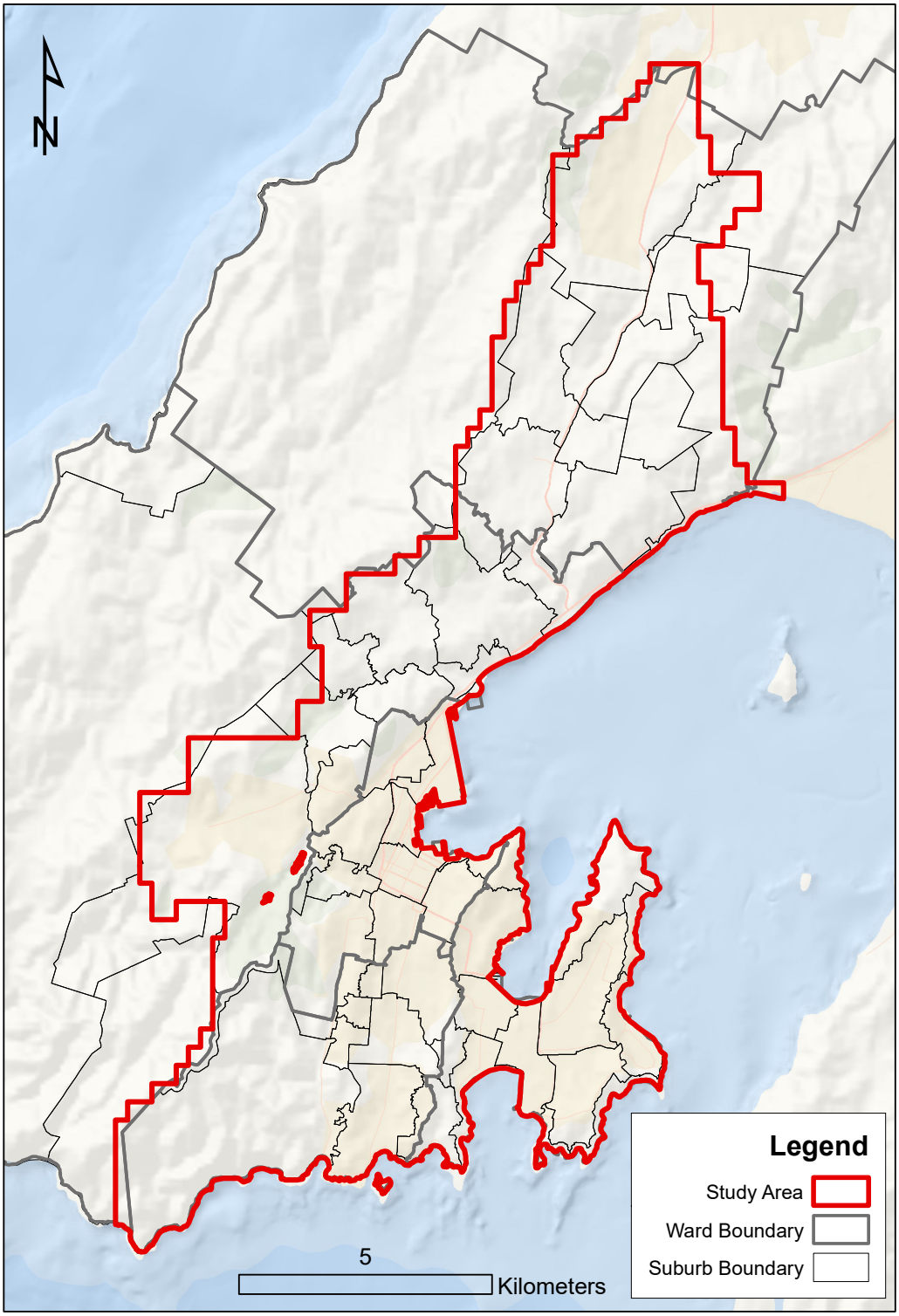
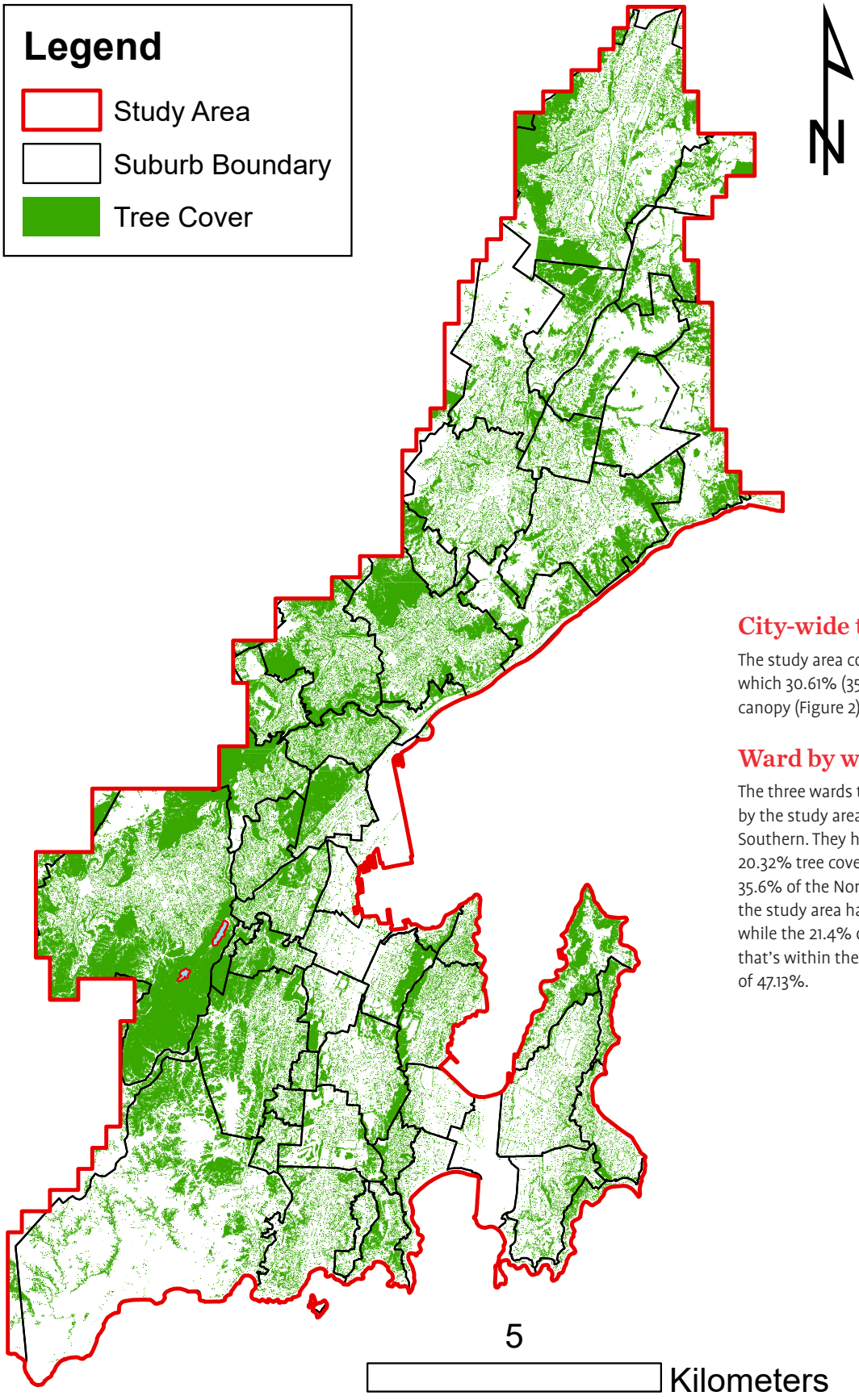


Figure 1 – The study area and suburb boundaries used to determine tree canopy cover in this study.

Results



City-wide tree cover

The study area covers 117.3 km² of land, of which 30.61% (35.9 km²) is covered by tree canopy (Figure 2).

Ward by ward tree cover

The three wards that are completely covered by the study area are Eastern, Lambton, and Southern. They have 20.92%, 33.76%, and 20.32% tree cover, respectively (Table 1). The 35.6% of the Northern ward that is within the study area has a tree cover of 27.07%, while the 21.4% of the Onslow-Western ward that's within the study area has a tree cover of 47.13%.

Figure 2 – Tree cover in Wellington City and Suburbs. 30.61% of land cover within the study site is covered by trees.

Table 1 – Tree canopy cover description within Wellington's wards.
** indicates wards that are not completely within the study area boundary; tree cover within these wards should be interpreted cautiously.*

Ward	Ward Area (km^2)	Area of ward covered by Study Area (km^2)	Proportion of ward covered by Study Area (%)	Tree cover within ward (km^2)	Tree cover within ward (%)
Eastern Ward	16.30	16.30	100.0	3.4094	20.92
Lambton Ward	12.97	12.97	100.0	4.3795	33.76
Northern Ward*	102.20	36.37	35.6	9.8441	27.07
Onslow-Western Ward*	136.44	29.19	21.4	13.7579	47.13
Southern Ward	22.19	22.19	100.0	4.5098	20.32

Suburb by suburb tree cover

Tree canopy cover is highly variable within Wellington's suburbs, ranging from 1 – 71% (*Table 2*). As noted in the table caption, not all suburbs were completely contained within the study area boundary, so the tree cover within those suburbs should be interpreted cautiously. In the reporting that follows, only suburbs that are completely contained within the study area boundary as considered.

The three suburbs with the greatest tree canopy cover are: (1) Highbury (71.3%); (2) Aro Valley (54.46%); and (3) Thorndon (48.93%). The three wards with the lowest tree canopy cover are: (1) Rongotai (1.17%); (2) Pipitea (2.86%), and Moa Point (3.12%). Two-thirds of the suburbs in the study area have tree cover ranging between 10 – 40% (Figure 3). Only two suburbs (5% of suburbs) have tree cover greater than 50%, while 6 (14% of suburbs) have tree cover less than 10%.

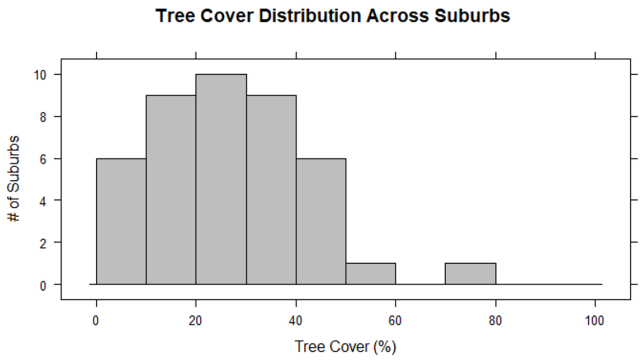


Figure 3 – Two-thirds of the suburbs in the study area have tree cover ranging between 10 – 40%. Only two suburbs have tree cover greater than 50%, while 6 have tree cover less than 10%.

*Table 2 – Tree canopy cover description within Wellington's suburbs. * indicates suburbs that are not completely within the study area boundary; tree cover within these suburbs should be interpreted cautiously. Table continues on following page.*

Suburb	Suburb Area (km^2)	Area of suburb covered by Study Area (km^2)	Proportion of suburb covered by Study Area (%)	Tree cover within suburb (km^2)	Tree cover within suburb (%)
Aro Valley	0.82	0.82	100.0	0.4466	54.46
Berhampore	1.67	1.67	100.0	0.3907	23.40
Breaker Bay	0.55	0.55	100.0	0.1087	19.77
Broadmeadows*	0.84	0.80	95.2	0.3137	39.21
Brooklyn*	14.45	5.53	38.3	2.0581	37.22
Churton Park*	3.97	3.87	97.6	0.5088	13.15
Crofton Downs*	1.42	1.25	88.2	0.4836	38.69
Glenside	2.06	2.06	100.0	0.8910	43.25
Grenada North*	2.57	1.51	58.8	0.4739	31.39
Grenada Village	2.41	2.41	100.0	0.6120	25.39
Hataitai	1.88	1.88	100.0	0.5412	28.79
Highbury	0.30	0.30	100.0	0.2139	71.30
Horokiwi*	7.17	3.11	43.4	0.9193	29.56
Houghton Bay	0.93	0.93	100.0	0.3022	32.50
Island Bay	2.75	2.75	100.0	0.5492	19.97
Johnsonville	3.85	3.85	100.0	0.7579	19.69
Kaiwharawhara	0.63	0.63	100.0	0.2034	32.28
Karaka Bays	0.46	0.46	100.0	0.1814	39.45
Karori*	15.40	11.00	71.4	6.0995	55.45
Kelburn	1.44	1.44	100.0	0.6035	41.91
Khandallah*	4.47	4.36	97.6	1.9687	45.15
Kilbirnie	1.09	1.09	100.0	0.1096	10.05
Kingston	0.49	0.49	100.0	0.1343	27.40
Lyall Bay	0.97	0.97	100.0	0.0847	8.73
Makara*	89.39	0.40	0.5	0.1920	48.00
Maupuia	1.96	1.96	100.0	0.8002	40.83
Melrose	0.52	0.52	100.0	0.2037	39.18
Miramar	2.86	2.86	100.0	0.3890	13.60
Moa Point	0.26	0.26	100.0	0.0081	3.12
Mornington	0.32	0.32	100.0	0.1237	38.65
Mount Cook	1.04	1.04	100.0	0.2465	23.70
Mount Victoria	1.20	1.20	100.0	0.4134	34.45
Newlands	4.43	4.43	100.0	1.4820	33.45
Newtown	2.11	2.11	100.0	0.5710	27.06
Ngaio*	3.19	3.07	96.2	1.4412	46.94
Ngauranga	2.13	2.13	100.0	0.5784	27.15
Northland	1.35	1.35	100.0	0.6430	47.63
Ohariu*	53.04	1.30	2.4	0.2669	20.53
Oriental Bay	0.33	0.33	100.0	0.1125	34.09
Owhiro Bay	12.88	12.88	100.0	2.0891	16.22
Paparangi	1.20	1.20	100.0	0.3470	28.92
Pipitea	1.39	1.39	100.0	0.0397	2.86
Rongotai	1.52	1.52	100.0	0.0178	1.17
Roseneath	0.53	0.53	100.0	0.1363	25.71
Seatoun	1.06	1.06	100.0	0.2345	22.13

Suburb	Suburb Area (km^2)	Area of suburb covered by Study Area (km^2)	Proportion of suburb covered by Study Area (%)	Tree cover within suburb (km^2)	Tree cover within suburb (%)
Southgate	0.44	0.44	100.0	0.0773	17.56
Strathmore Park	1.95	1.95	100.0	0.3490	17.90
Takapu Valley*	10.28	1.50	14.6	0.4077	27.18
Tawa*	10.15	9.11	89.8	2.9680	32.58
Te Aro	1.20	1.20	100.0	0.0650	5.42
Thorndon	1.47	1.47	100.0	0.7192	48.93
Vogeltown	0.27	0.27	100.0	0.0918	34.00
Wadestown	1.41	1.41	100.0	0.6586	46.71
Wellington Central	0.66	0.66	100.0	0.0466	7.06
Wilton*	2.51	1.60	63.7	0.9538	59.61
Woodridge	2.10	2.10	100.0	0.2721	12.96
Total	**287.78**	**117.30**	**40.7**	**35.9012**	**30.61**

Accuracy of tree cover classification

The automated classification, using the OBIA technique, followed by manual refinement resulted in an overall classification accuracy of 98.36% (*Table 3*). This means that 98.36% of the 2500 random points were classified correctly as tree cover or other land covers.

Table 3 – The error matrix showing the results of the accuracy assessment for the final classification, after manual refinement.

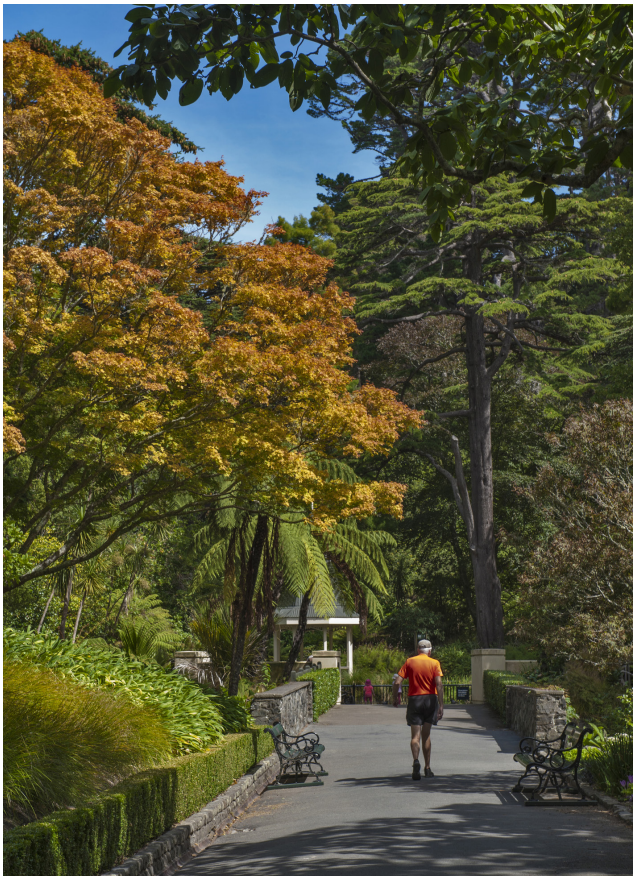
		Classified land cover		
		Tree cover	Other land cover	Producer's Accuracy
Reference land cover	Tree cover	687	20	97.17%
	Other land cover	21	1772	98.83%
	User's Accuracy	97.03%	98.88%	

- Overall Accuracy = 98.36%
- Commission Error (Trees) = 1 – User's Accuracy = 2.97%
- Omission Error (Trees) = 1 – Producer's accuracy = 2.83%

For a definition of these terms, see the Glossary

Tree canopy cover classification achieved a high accuracy (Producer's accuracy – 97.17%, User's accuracy = 97.03%). What this means is that if you were to locate a point on the map, and that point were to show that tree cover was present, then roughly 97 times out of 100, there would be tree cover at that location in reality.

It's important to accept that despite the high overall accuracy of the approach, many errors do still exist. Any approach to tree cover classification has inherent error. Those errors can take the form of misclassifications, or of incorrectly delineated tree canopy. To minimise this error, manual refinement was undertaken as part of this work, but for efficiency, it was undertaken at a scale of no greater than 1:2500, whereby relatively large misclassification and boundary inaccuracies are more likely to be identified and corrected than smaller inaccuracies. Where misclassification errors occurred, trees were mostly misclassified as buildings and/or scrub (or vice-versa).



Where delineation errors occurred, non-tree-canopy areas with similar height and/or spectral features to the trees were incorrectly included in the tree canopy area. This commonly occurred where trees were adjacent to buildings or other tall infrastructure (e.g. street lights), or where trees were surrounded by shorter, but spectrally similar vegetation (e.g. shrubs).

Summary of key results

This report has identified a number of key results. These include:

- 30.61% of all land within the study area is covered by trees
- Tree canopy cover is highly variable across the study area, particularly at the scale of suburbs
  - Tree cover ranges from 20.32 – 47.13% in the five wards
  - Tree cover ranges from approximately 1 – 71% in the 56 suburbs
    - Rongotai has only 1% canopy cover, whereas Highbury has 71%
    - Two-thirds of the suburbs in the study area have tree cover ranging between 10 – 40%
    - Only two suburbs (5% of suburbs) have tree cover greater than 50%
    - Six suburbs (14% of suburbs) have tree cover less than 10%
- The accuracy assessment shows that the overall accuracy achieved by the tree cover classification was 98.36%

Next Steps

This canopy cover assessment should be considered as a step towards informing the policy and strategic management of urban forest within Wellington City and Suburbs. Future work could include:

- **Manual editing**
  As evidenced by the accuracy assessment, there are small errors in the tree cover classification. These errors can only be corrected via further manual editing. Depending on future uses of this data, manual correction may be desirable or necessary.
- **TCC comparison**
  Tree canopy cover in Wellington City and Suburbs could be compared with relevant cities worldwide. Knowing what tree cover is in cities with comparable characteristics (e.g. climate, population), could help Wellington set appropriate tree canopy cover targets.
- **TCC comparison within Wellington**
  Comparing tree canopy cover across different spatial units (e.g. parks, road reserves) could lead to prioritising planting programs in areas with low canopy cover, or prioritising tree maintenance budgets in areas with high tree cover.
- **From 2D to 3D urban forest structure**
  TCC is widely used to describe urban forest structure. However, it is limited because it only provides a two-dimensional representation of tree structure. For example, the canopy area of an ornamental cherry tree and a columnar Lombardy poplar tree may be the same; but the crown volume and leaf area of the Lombardy poplar will be vastly greater. Because most ecosystem services are linked to leaf area, canopy volume is a much better metric to describe urban forest structure than canopy cover. With the LiDAR data available for the study area, it would be possible to produce a canopy volume estimate for Wellington City and Suburbs.
- **Determining Wellington's potential tree cover increase**
  By quantifying available planting space within Wellington City and Suburbs that is not currently covered by trees, it is possible to determine the maximum potential tree canopy cover. This will help in establishing achievable tree canopy cover goals.
- **Quantifying tree species diversity**
  Understanding tree species diversity is used by many councils globally to inform planting strategy and to mitigate risk from climate change, pests, or disease.
- **Regular monitoring**
  Tree canopy cover should continue to be monitored regularly. Using an approach comparable to that undertaken in this report relies on the regular acquisition of aerial photography and LiDAR. Should aerial photography and LiDAR be unavailable in the future, a ground-based approach (e.g. using a NZ version of i-Tree) could be employed. Regular monitoring of changes in tree cover can help to assess whether current policies/management are effective, and inform future policies/management.

Glossary

Object-based image analysis: a method for automatically classifying remotely-sensed imagery (e.g. aerial photography, LiDAR data) into land covers of interest (e.g. trees, buildings, roads, grasslands). Imagery is segmented into 'objects' (based on minimising the within-object variation in spectral or other characteristics). Objects are then classified as a land cover of interest.

Commission error: objects that were classified as a particular land cover (e.g. tree), but should not have been (e.g. the object was actually a building). Commission errors are calculated separately for each land cover class. See figure below for an example.

Omission error: objects that were not classified as a particular land cover, but should have been. For example, a tree in the imagery was not classified as a tree, but instead as a building. Omission errors are calculated separately for each land cover class. See figure below for an example.

From the perspective of tree cover accuracy, the image at left shows a commission error – an object that is not a tree (it is a building) has been classified as a tree. The image at right shows an omission error – an object that is a tree has not been classified as a tree, it has been classified as a building.

95% confidence interval: a range of values defining an upper and lower limit, such that there is a 95% probability that the value of a parameter lies within it.

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